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He et al.

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(54) **DOWNLINK RESOURCE SCHEDULING**

(75) Inventors: **Hong He**, Beijing (CN); **Jong-Kae Fwu**, Sunnyvale, CA (US)

(73) Assignee: **Intel Corporation**, Santa Clara, CA (US)

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H04W 72/02 (2009.01)
H04W 72/12 (2009.01)

(52) **U.S. Cl.**
CPC ***H04W 72/042*** (2013.01); ***H04W 72/02*** (2013.01); *H04W 72/12* (2013.01)

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USPC 370/328, 329
See application file for complete search history.

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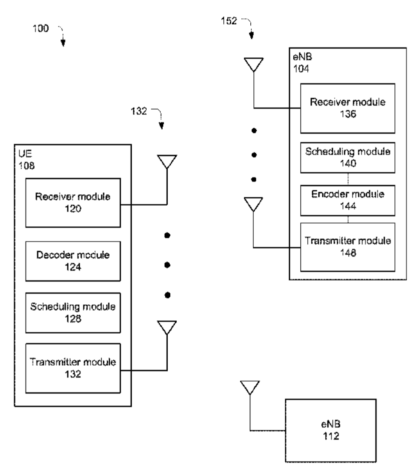
Primary Examiner — Alpus H Hsu
Assistant Examiner — Dharmesh Patel
(74) *Attorney, Agent, or Firm* — Schwabe, Williamson & Wyatt, P.C.

(57) **ABSTRACT**

Embodiments of the present disclosure describe devices, methods, computer-readable media and systems configurations for downlink resource scheduling in wireless networks. In some embodiments, the scheduling may include multi-subframe cross carrier scheduling utilizing downlink control information. Other embodiments may be described and/or claimed.

17 Claims, 8 Drawing Sheets



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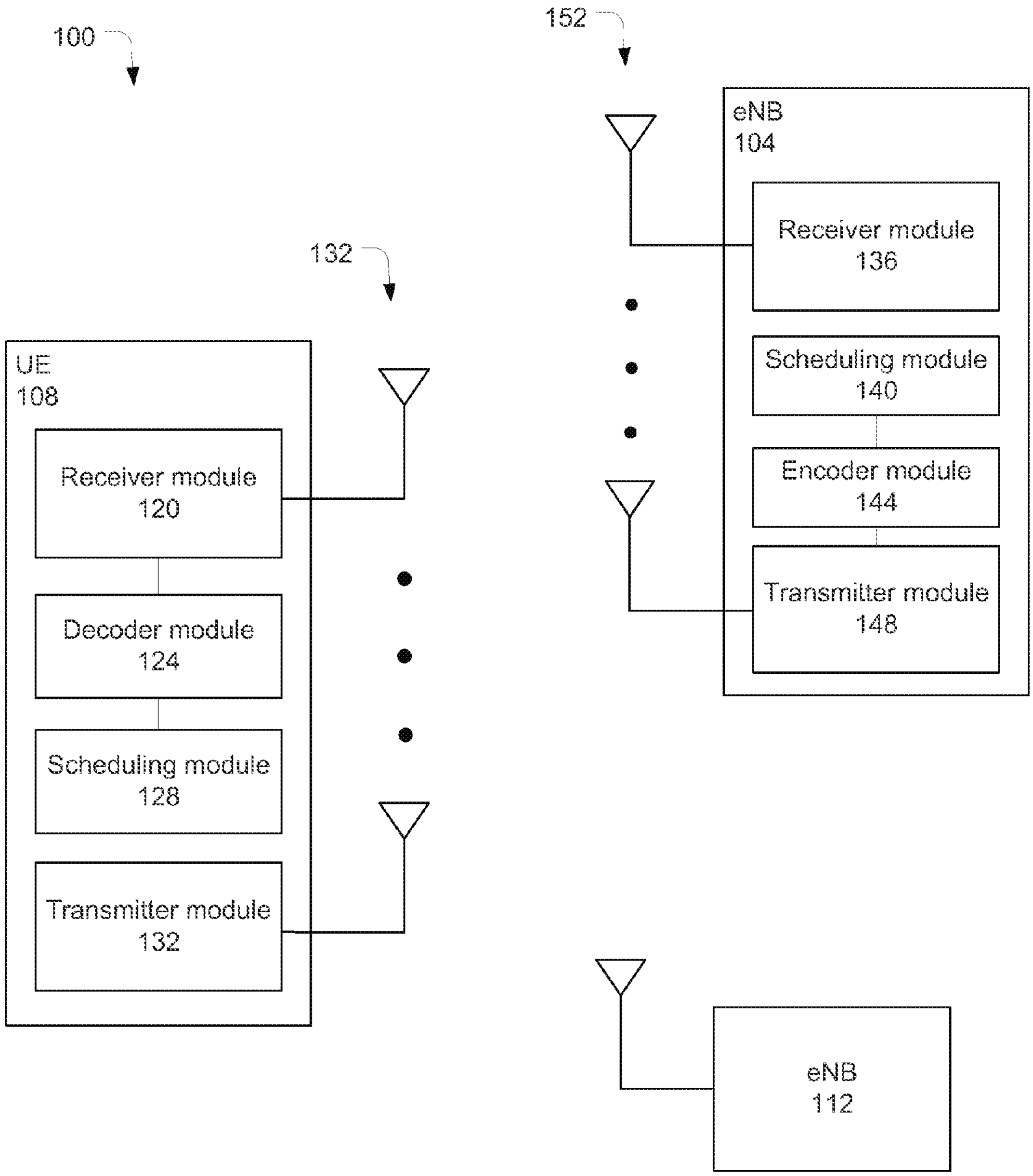
100
152
132
eNB
104
Receiver module
136
Scheduling module
140
Encoder module
144
Transmitter module
148
UE
108
Receiver module
120
Decoder module
124
Scheduling module
128
Transmitter module
132
eNB
112

Figure 1

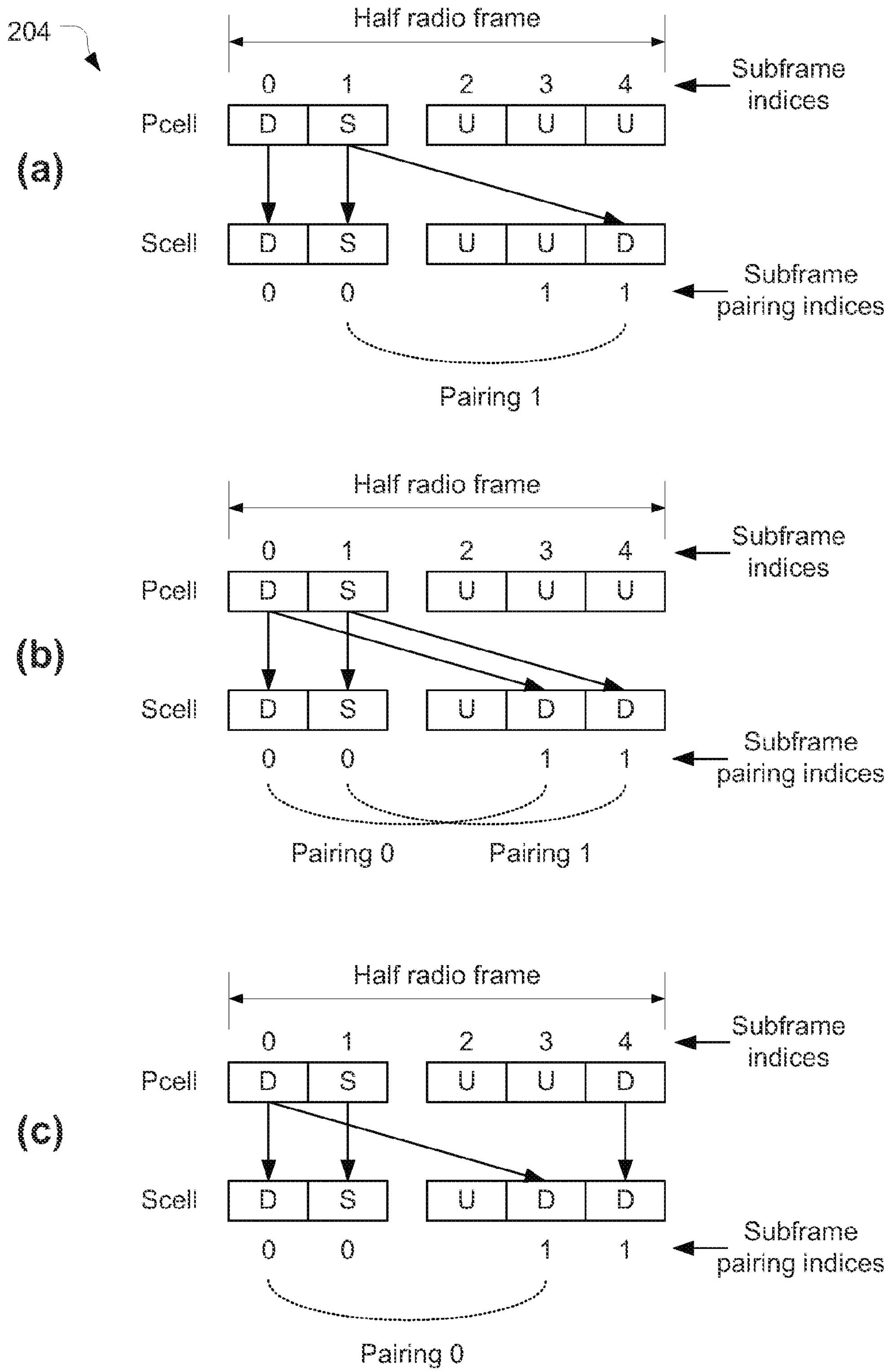
204
(a)
Half radio frame
0 1 2 3 4
Subframe indices
Pcell
D S U U U
Scell
D S U U D
0 0 1 1
Subframe pairing indices
Pairing 1
(b)
Half radio frame
0 1 2 3 4
Subframe indices
Pcell
D S U U U
Scell
D S U D D
0 0 1 1
Subframe pairing indices
Pairing 0
Pairing 1
(c)
Half radio frame
0 1 2 3 4
Subframe indices
Pcell
D S U U D
Scell
D S U D D
0 0 1 1
Subframe pairing indices
Pairing 0

Figure 2

300

CIF (3-bits)	CA Level			
	2	3	4	5
000	CC_0	CC_0	CC_0	CC_0
001	CC_1, '0'	CC_1, '0'	CC_1, '0'	CC_1, '0'
010	CC_1, '1'	CC_1, '1'	CC_1, '1'	CC_1, '1'
011	CC_1, '0,1'	CC_1, '0,1'	CC_2, '0'	CC_2, '0'
100	Reserved	CC_2, '0'	CC_2, '1'	CC_2, '1'
101	Reserved	CC_2, '1'	CC_3, '0'	CC_3, '0'
110	Reserved	CC_2, '0,1'	CC_3, '1'	CC_3, '1'
111	Reserved	Reserved	Reserved	CC_4, '0'

Figure 3

404

CIF (3-bits)	CA Level			
	2	3	4	5
000	CC_0	CC_0	CC_0	CC_0
001	CC_1, '0'	CC_1, '0'	CC_1, '0'	CC_1, '0'
010	CC_1, '1'	CC_1, '1'	CC_1, '1'	CC_1, '1'
011	CC_1, '0,1'	CC_1, '0,1'	CC_1, '0,1'	CC_1, '0,1'
100	Reserved	CC_2, '0'	CC_2, '0'	CC_2, '0'
101	Reserved	CC_2, '1'	CC_2, '1'	CC_2, '1'
110	Reserved	CC_2, '0,1'	CC_3, '0'	CC_3, '0'
111	Reserved	Reserved	CC_3, '1'	CC_4, '0'

408

CIF (3-bits)	CA Level			
	2	3	4	5
000	CC_0	CC_0	CC_0	CC_0
001	CC_1, '0'	CC_1, '0'	CC_1, '0'	CC_1, '0'
010	CC_1, '1'	CC_1, '1'	CC_1, '1'	CC_1, '1'
011	CC_1, '0,1'	CC_1, '0,1'	CC_1, '0,1'	CC_1, '0,1'
100	Reserved	CC_2, '0'	CC_2, '0'	CC_2, '0'
101	Reserved	CC_2, '1'	CC_2, '1'	CC_2, '1'
110	Reserved	CC_2, '0,1'	CC_2, '0,1'	CC_3, '0'
111	Reserved	Reserved	CC_3, '0'	CC_4, '0'

Figure 4

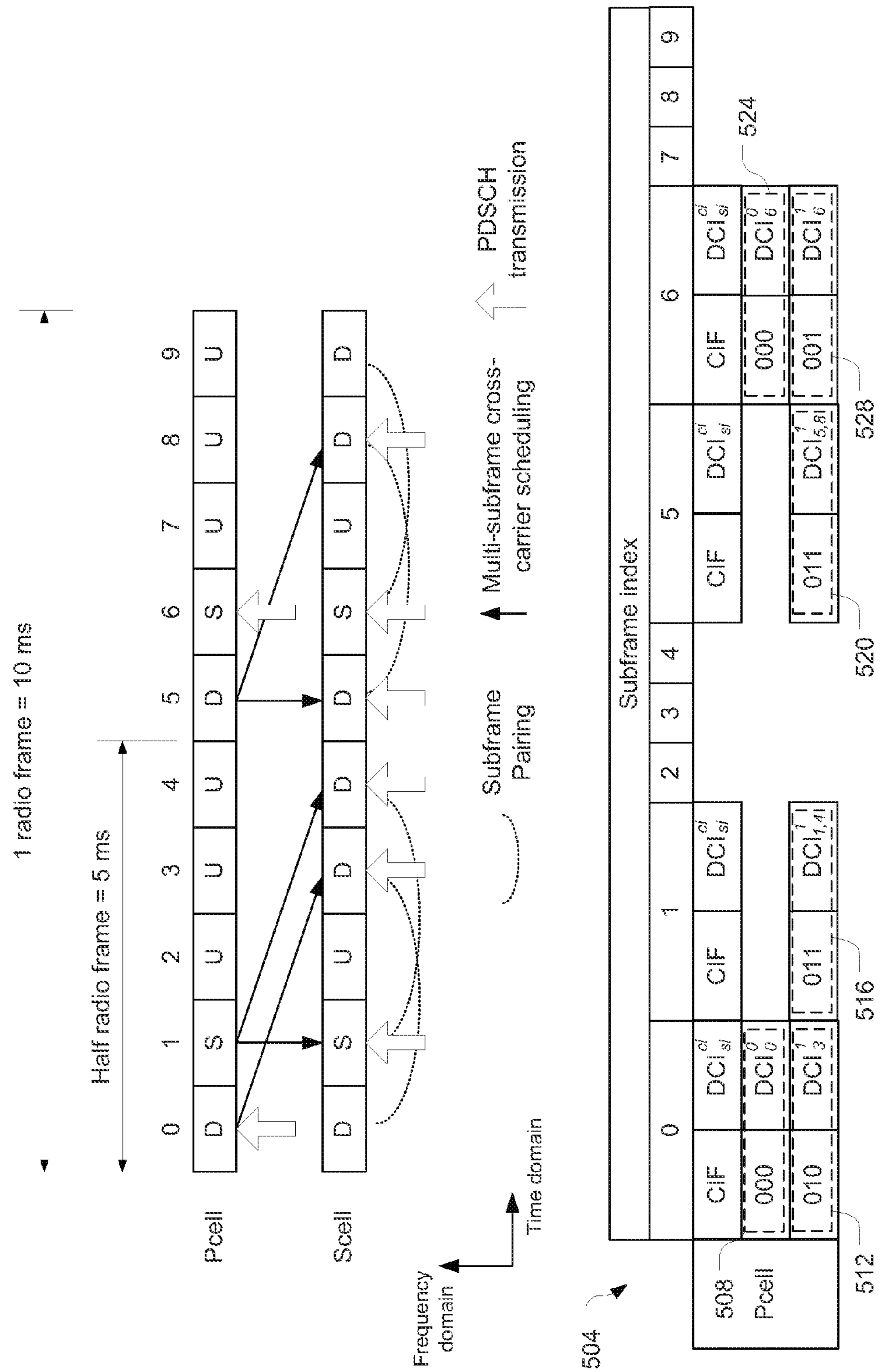
1 radio frame = 10 ms
Half radio frame = 5 ms
0
1
2
3
4
5
6
7
8
9
Pcell
Scell
D
S
U
Frequency domain
Time domain
Subframe Pairing
Multi-subframe cross-carrier scheduling
PDSCH transmission
Subframe index
504
508
Pcell
CIF
DCI^{ci}_{si}
000
DCI^{0}_{0}
010
DCI^{1}_{3}
011
$DCI^{1}_{1,4}$
$DCI^{1}_{5,8}$
001
DCI^{0}_{6}
DCI^{1}_{6}
512
516
520
524
528

Figure 5

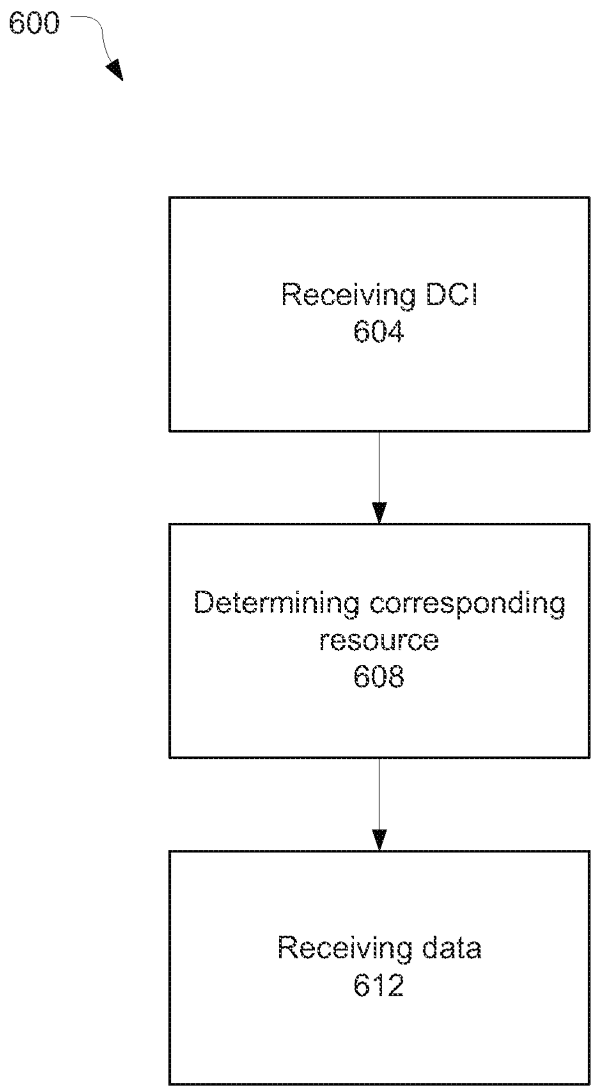
600
Receiving DCI
604
Determining corresponding resource
608
Receiving data
612

Figure 6

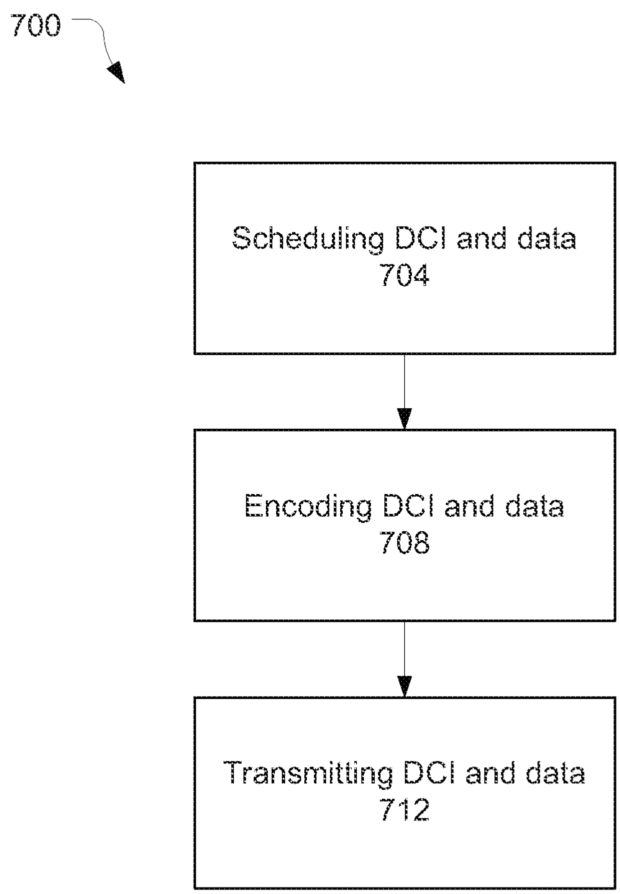
700
Scheduling DCI and data
704
Encoding DCI and data
708
Transmitting DCI and data
712

Figure 7

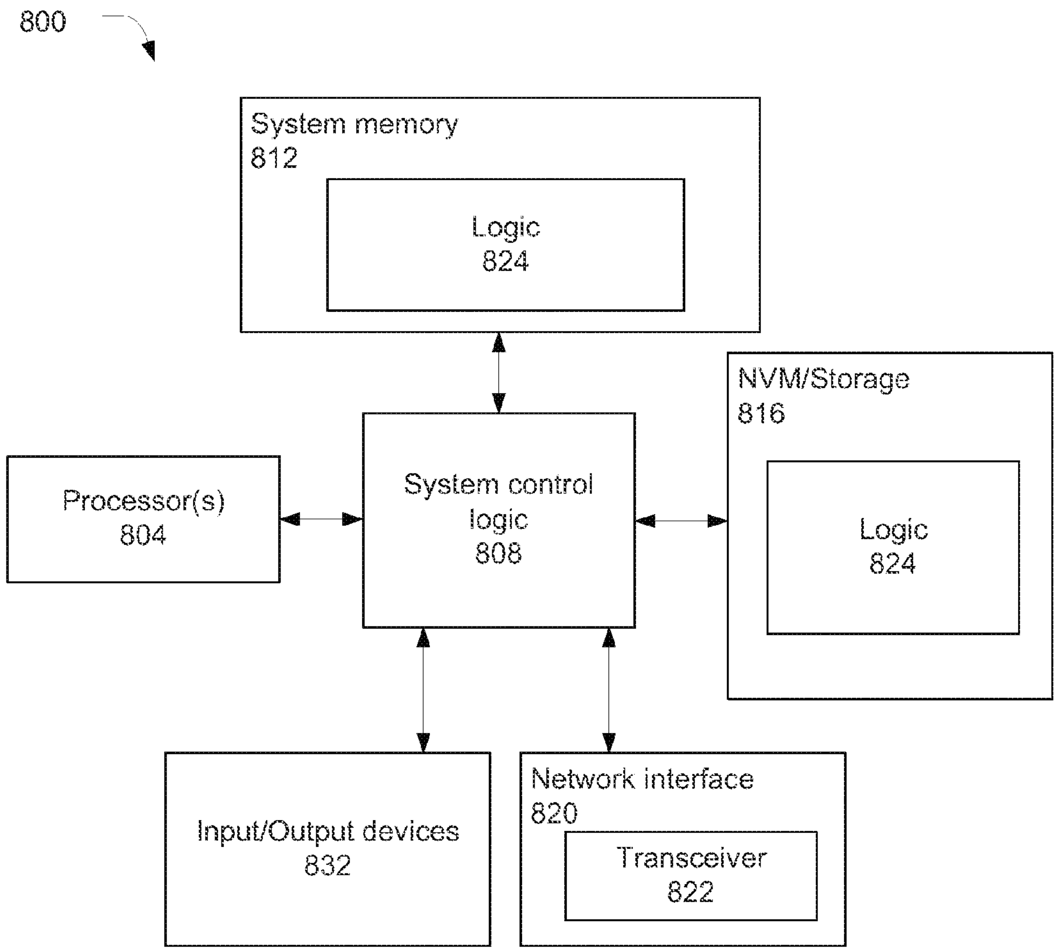
800
System memory
812
Logic
824
NVM/Storage
816
Processor(s)
804
System control
logic
808
Logic
824
Input/Output devices
832
Network interface
820
Transceiver
822

Figure 8

DOWNLINK RESOURCE SCHEDULING

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a national phase entry under 35 U.S.C. §371 of International Application No. PCT/US2012/031036, filed Mar. 28, 2012, entitled "DOWNLINK RESOURCE SCHEDULING", which designates the United States of America, and which claims priority to U.S. Provisional Patent Application No. 61/556,109, filed Nov. 4, 2011, the entire contents and disclosure of which are hereby incorporated by reference in their entireties.

FIELD

Embodiments of the present invention relate generally to the field of communications, and more particularly, to downlink resource scheduling in wireless communication networks.

BACKGROUND

In 3rd Generation Partnership Project (3GPP) long-term evolution (LTE) Release 10 (March 2011), which may also be referred to as LTE-Advanced (LTE-A), heterogeneous networks (HetNets) are relied upon to provide high-throughput communications. HetNets may include cells of different power class, e.g., macro, pico, or femto, and access class, e.g., open or closed-subscriber group (CSG). To accommodate for lack of intercell interference coordination (ICIC) control signaling in 3GPP LTE Release 8 (September 2009), multicarrier operation with cross-carrier scheduling was provided. This would allow for the control information applicable to a subframe of a first component carrier, being transmitted in the corresponding subframe of another component carrier that was deemed more reliable. A single subframe cross-carrier scheduling operation is facilitated by use of a carrier identification field (CIF) of UE dedicated downlink control information (DCI) to provide improved control reliability and enable enhanced ICIC (eICIC) for HetNets.

In 3GPP LTE Release 11, each component carrier may have its own time-division duplexing (TDD) uplink-downlink (UL-DL) configuration. However, aggregation of carriers with different TDD UL-DL configurations may complicate cross-carrier scheduling.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals designate like structural elements. Embodiments are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings.

FIG. **1** schematically illustrates a wireless communication network in accordance with various embodiments.

FIGS. **2**(*a*)-**2**(*c*) schematically illustrate scheduling scenarios in accordance with various embodiments.

FIG. **3** illustrates a multi-subframe cross carrier scheduling (MSCC) table in accordance with various embodiments.

FIG. **4** illustrates MSCC tables in accordance with various embodiments.

FIG. **5** illustrates an MSCC scheduling of a radio frame in accordance with various embodiments.

FIG. **6** is a flowchart illustrating an operation of a user equipment in accordance with various embodiments.

FIG. **7** is a flowchart illustrating an operation of a base station in accordance with various embodiments.

FIG. **8** schematically depicts an example system in accordance with various embodiments.

DETAILED DESCRIPTION

Illustrative embodiments of the present disclosure include, but are not limited to, methods, systems, and apparatuses for downlink resource scheduling in wireless networks.

Various aspects of the illustrative embodiments will be described using terms commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. However, it will be apparent to those skilled in the art that alternate embodiments may be practiced with only some of the described aspects. For purposes of explanation, specific numbers, materials, and configurations are set forth in order to provide a thorough understanding of the illustrative embodiments. However, it will be apparent to one skilled in the art that alternate embodiments may be practiced without the specific details. In other instances, well-known features are omitted or simplified in order not to obscure the illustrative embodiments.

Further, various operations will be described as multiple discrete operations, in turn, in a manner that is most helpful in understanding the illustrative embodiments; however, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation.

The phrase "in some embodiments" is used repeatedly. The phrase generally does not refer to the same embodiments; however, it may. The terms "comprising," "having," and "including" are synonymous, unless the context dictates otherwise. The phrase "A and/or B" means (A), (B), or (A and B). The phrase "A/B" means (A), (B), or (A and B), similar to the phrase "A and/or B". The phrase "at least one of A, B and C" means (A), (B), (C), (A and B), (A and C), (B and C) or (A, B and C). The phrase "(A) B" means (B) or (A and B), that is, A is optional.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent implementations may be substituted for the specific embodiments shown and described, without departing from the scope of the embodiments of the present disclosure. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that the embodiments of the present disclosure be limited only by the claims and the equivalents thereof.

As used herein, the term "module" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality.

FIG. **1** schematically illustrates a wireless communication network **100** in accordance with various embodiments. Wireless communication network **100** (hereinafter "network **100**") may be an access network of a 3rd Generation Partnership Project (3GPP) long-term evolution advanced (LTE-A) network such as evolved universal mobile telecommunication system (UMTS) terrestrial radio access network (E-UTRAN). The network **100** may include a base station, e.g., enhanced node base station (eNB) **104**, configured to wirelessly communicate with a mobile terminal, e.g., user equipment (UE) **108**. While embodiments of the present invention are described with reference to an LTE-A network, some embodiments may be used with other types of wireless access networks.

In embodiments in which the UE **108** is capable of utilizing carrier aggregation (CA), a number of component carriers (CCs) may be aggregated for communication between the eNB **104** and the UE **108**. In an initial connection establishment, the UE **108** may connect with a primary serving cell (Pcell) of the eNB **104** utilizing a primary CC, which may also be referred to as CC_**0**. This connection may be used for various functions such as security, mobility, configuration, etc. Subsequently, the UE **108** may connect with one or more secondary serving cells (Scells) of the eNB **104** utilizing one or more secondary CCs. These connections may be used to provide additional radio resources.

In some embodiments, one or more additional eNBs, e.g., eNB **112**, may be employed, e.g., in a HetNet configuration. In some embodiments, the eNBs of a HetNet may each have different power and/or access classes. For example, in one embodiment the eNB **104** may be a relatively high-power base station such as a macro eNB, while the eNB **112** may be a relatively low-power base station, e.g., a pico eNB and/or femto eNB.

eNB **112** may have a Pcell and one or more Scell(s) similar to eNB **104**. However, the same CCs will not be used for Pcells for the two base stations of the HetNet. For example, if the eNB **104** has CC_**0** for its Pcell and CC_**1** for its Scell, eNB **112** may have CC_**1** for its Pcell and CC_**0** for its Scell.

The UE **108** may include a receiver module **120**, a decoder module **124**, a scheduling module **128**, and a transmitter module **132** coupled with one another at least as shown. In some embodiments, the decoder module **124** and/or scheduling module **128** may be incorporated into the receiver module **120**. Briefly, the decoder module **124** may operate to decode downlink transmissions received via the Pcell or the Scell, while the scheduling module may operate to identify transmissions, within the downlink, that are scheduled for the UE **108**. The receiver module **120** and transmitter module **132** may each be further coupled with one or more of a plurality of antennas **132** of the UE **108**.

The UE **108** may include any number of suitable antennas. In various embodiments, the UE **108** may include at least as many antennas as a number of simultaneous spatial layers or streams received by the UE **108** from the eNBs, although the scope of the present disclosure may not be limited in this respect. The number of simultaneous spatial layers or streams may also be referred to as transmission rank, or simply rank.

One or more of the antennas **132** may be alternately used as transmit or receive antennas. Alternatively, or additionally, one or more of the antennas **132** may be dedicated receive antennas or dedicated transmit antennas.

eNB **104** may include receiver module **136**, scheduling module **140**, encoder module **144**, and transmitter module **148** coupled with one another at least as shown. In some embodiments, scheduling module **140** and/or encoder module **144** may be incorporated into the transmitter module **148**. Receiver module **136** and transmitter module **148** may each be further coupled with one or more of a plurality of antennas **152** of the eNB **104**. The eNB **104** may include any number of suitable antennas. In various embodiments, the eNB **104** may include at least as many antennas as a number of simultaneous transmission streams transmitted to the UE **108**, although the scope of the present disclosure may not be limited in this respect. One or more of the antennas **152** may be alternately used as transmit or receive antennas. Alternatively, or additionally, one or more of the antennas **152** may be dedicated receive antennas or dedicated transmit antennas.

Though not shown explicitly, the eNB **112** may include modules/components similar to those of the eNB **104**.

With cross-carrier scheduling of a physical downlink shared channel (PDSCH), downlink control information (DCI) transmitted in the Pcell may provide downlink grant information pertaining to the Pcell or one of the Scells. The downlink grant information may be an indication of a downlink resource of the PDSCH that is to include data directed to the UE **108** through the corresponding serving cell. The DCI may include a carrier indication field (CIF) whose value indicates to which serving cell the downlink grant information pertains.

Conventionally, cross-carrier scheduling is restricted to downlink grant information being only applicable to subframes in which the DCI is transmitted. For example, DCI transmitted in subframe **1** would apply only to subframe **1**, though it could be any serving cell.

Various embodiments provide for multi-subframe cross-carrier (MSCC) scheduling on PDSCH. This may allow for DCI transmitted in a first subframe of the Pcell, to be applicable to a second subframe in one of the Scells that occurs later in the frame sequence than the first subframe. The MSCC described herein may even be used with CCs having different TDD UL/DL configuration. In some embodiments, this MSCC scheduling may be supported without increasing the DCI overhead to avoid DCI detection performance degradation. This may be done, in part through provision of predetermined subframe pairings as will be described.

MSCC scheduling may include predetermined subframe pairings (x, y) in each half radio frame. The pairings may include a first pairing (**0**, **3**) and a second pairing (1, 4). These particular pairings may provide equal processing latency between the paired subframes. However, other embodiments may include other pairings.

Generally, the predetermined subframe pairings may provide the option of DCI, and DL grant information within the DCI, in particular, transmitted in x subframe of the Pcell, identifying a downlink resource in the y subframe of the Scell. In some embodiments, the subframe pairing may only be implemented in the event that specific TDD UL/DL configurations of the CCs prevent transmission of DL grant information according to the conventional mechanism, i.e., transmitting DL grant information for the Scell in the same subframe of the Pcell.

Embodiments provide that if the Pcell subframe y is a DL subframe, then the DCI for subframe y will be transmitted at Pcell subframe y. However, if the Pcell subframe y is an UL subframe, thereby preventing transmission of DL grant information, then the DCI for subframe y of the Scell will be transmitted at Pcell subframe x. This may be seen with reference to scenarios depicted in FIGS. **2**(*a*)-**2**(*c*).

FIG. **2**(*a*) illustrates a scenario in which a Pcell has a TDD configuration **0** with subframe **0** being a downlink subframe (D), subframe **1** being a special subframe (S), and subframes **2-4** being uplink subframes (U). The TDD configurations may be defined by table 1 below.

TABLE 1

TDD	Subframe number									
configuration	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
2	D	S	U	D	D	D	S	U	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

The special subframe may include three fields: downlink pilot time slot (DwPTS), which may include the DCI, guard period (GP), and uplink pilot time slot (UpPTS).

The Scell of FIG. **2**(*a*) has a TDD configuration **1** with subframes **0** and **4** being downlink subframes, subframe **1** being a special subframe, and subframes **2** and **3** being uplink subframes.

In some embodiments, subframe **0** of the Pcell may include DCI that identifies a downlink resource in subframe **0** of the Scell. It may be noted that subframe pairing with respect to (**0**, **3**) is not required given that the 3rd subframe of the Scell is an uplink subframe and, therefore, will not need DL grant information.

Subframe **1** of the Pcell may include DCI that identifies a downlink resource in subframe **1** of the Scell and/or subframe **4** of the Scell. Subframe pairing (**1**, **4**) may be implemented, in this case, because the subframe y of the Pcell, i.e., subframe **4**, is an uplink subframe.

FIG. **2**(*b*) illustrates a scenario in which a Pcell has a TDD configuration **0** with subframe **0** being a downlink subframe, subframe **1** being a special subframe, and subframes **2**-**4** being uplink subframes. The Scell has a TDD configuration **2** with subframes **0**, **3**, and **4** being downlink subframes, subframe **2** being a special subframe, and subframe **2** being an uplink subframe.

Subframe **0** of the Pcell may include DCI that identifies a downlink resource in subframe **0** and/or subframe **3** of the Scell. The subframe pairing (**0**, **3**) may be implemented in this case because the subframe y of the Pcell, i.e., subframe **3**, is an uplink subframe. Unlike the scenario of FIG. **2**(*a*), subframe **3** of the Scell is a downlink subframe and may therefore receive a DL grant.

Subframe **1** of the Pcell may include DCI that identifies a downlink resource in subframe **1** and/or subframe **4** of the Scell. The subframe pairing (**1**, **4**) may be implemented in this case because the subframe y of the Pcell, i.e., subframe **4**, is an uplink subframe.

FIG. **2**(*c*) illustrates a scenario in which a Pcell has a TDD configuration **1** with subframes **0** and **4** being downlink subframes, subframe **1** being a special subframe, and subframes **2** and **3** being uplink subframes. The Scell has a TDD configuration **2** with subframes **0**, **3**, and **4** being downlink subframes, subframe **2** being a special subframe, and subframe **2** being an uplink subframe.

Subframe **0** of the Pcell may include DCI that identifies a downlink resource in subframe **0** and/or subframe **3** of the Scell. The subframe pairing (**0**, **3**) may be implemented in this case because the subframe y of the Pcell, i.e., subframe **3**, is an uplink subframe and subframe **3** of the Scell is a downlink subframe.

Subframe **1** of the Pcell may include DCI that identifies a downlink resource in subframe **1**. The subframe pairing (**1**, **4**) may not be implemented in this case because the subframe y of the Pcell, i.e., subframe **4**, is a downlink subframe. Therefore, subframe **4** of the Pcell may include DCI for subframe **4** of the Scell.

MSCC scheduling may be facilitated by use of MSCC table **300** shown in FIG. **3** in accordance with some embodiments. MSCC table **300** may include mapping information for individual combinations of 3-bit CIF values and carrier aggregation levels as shown. The carrier aggregation level may refer to how many CCs, or serving cells, are configured for communication between the eNB **104** and the UE **108**. The values within MSCC table **300** include designated CC, e.g., CC_**0**, CC_**1**, CC_**2**, or CC_**3**, and subframe pairing index, e.g., **0** and/or **1**.

If DCI includes a CIF value of ‘000,’ the DCI information may pertain to the Pcell, i.e., CC_**0**. If DCI includes a CIF value of ‘001,’ the DCI information may pertain to the first subframe of the subframe pair of the Scell, CC_**1**. For example, with reference to FIG. **2**(*b*), if DCI was transmitted in subframe **0** of the Pcell and included a CIF value of ‘001,’ then the downlink grant information would identify a downlink resource in subframe **0** of the Scell. If the DCI was transmitted in subframe **1** of the Pcell and included the same CIF value, then the downlink grant information would identify a downlink resource in subframe **1** of the Scell.

If DCI includes a CIF value of ‘010,’ the DCI information may pertain to the second subframe of the subframe pair of the Scell, CC_**1**. For example, with reference to FIG. **2**(*b*), if DCI was transmitted in subframe **0** of the Pcell and included a CIF value of ‘010,’ then the downlink grant information would identify a downlink resource in subframe **3** of the Scell. If the DCI was transmitted in subframe **1** of the Pcell and included the same CIF value, then the downlink grant information would identify a downlink resource in subframe **4** of the Scell.

If DCI includes a CIF value of ‘011’ and the CA level is either two or three, the DCI information may pertain to the first and second subframes of the subframe pair of the Scell, CC_**1**. For example, with reference to FIG. **2**(*b*), if DCI transmitted in subframe **0** of the Pcell and included a CIF value of ‘011,’ then the downlink grant information would identify a downlink resource in both subframes **0** and **3** of the Scell.

If DCI includes a CIF value of ‘011’ and the CA level is either four or five, the DCI information may pertain to the first subframe of the subframe pair of a second Scell, CC_**2**. The remaining mapping information may be interpreted in similar manners.

The CIF in MSCC table **300** is provided as a 3-bit value in order to be compatible with existing 3-bit CIF fields of DCI in LTE REL 10. While the eight states provided by the 3-bit value may not be enough to include every possible combination of CC/subframe index, it may be sufficient to account for the majority of desired scheduling operations.

In some embodiments, CIF may be represented by more or less than 3 bits. In the event that CIF is represented by more than 3 bits, trade-offs between DCI decoding efficiency and increased MSCC scheduling represented by additional CIF states may be considered.

The values selected to be included in a particular table may reflect a particular Scell priority scheme. In general, the tables may reflect a bias toward lower-level Scells based on an assumption that the eNB **104** will likely schedule PDSCH of the lowest Scells first. This may be due to some deployment scenarios utilizing a lower frequency band for the first Scell than for the subsequent Scells. However, different Scell priority schemes may prioritize different Scells in different manners.

Tables **404** and **408** of FIG. **4** reflect various Scell priority schemes, which illustrate some of the flexibility that may be incorporated into the design of tables used in various embodiments.

Table **404** provides an Scell priority scheme in which the first Scell, CC_**1**, is prioritized. Therefore, each possible subframe pairing index, e.g., '0', '1', and '0,1', is provided for each CA level. If the CA level is four or greater, then the dual subframe scheduling, i.e., scheduling both subframes of the pair, is not supported for the higher CCs, e.g., CC_**2**, CC_**3** and CC_**4**. Furthermore, when the CA level is five, the scheduling of the second value of the subframe pair is not supported for either CC_**3** or CC_**4**.

Table **408** provides an Scell priority scheme in which first and second Scells are prioritized if the CA level is four or greater. If the CA level is four, then only the first value of the subframe pair is supported for CC_**3**. If the CA level is five, then only the first value of the subframe pair is supported for CC_**3** and CC_**4**, and the dual subframe scheduling is not supported for CC_**2**.

FIG. **5** illustrates an MSCC scheduling of a radio frame in which a Pcell and an Scell are configured for communication in accordance with some embodiments. The radio frame is a 10 ms radio frame with PDSCH transmissions on subframes **0** and **6** of the Pcell and subframes **1**, **3**, **4**, **5**, **6**, and **8** of the Scell.

Chart **504** illustrates specific DCI that include CIF values and associated indicators. The MSCC scheduling reflected in the embodiment of FIG. **5** may be based on table **300**.

Subframe **0** of the Pcell may include, e.g., in a PDCCH transmission, DCI **508** and **512**. Each DCI may include a CIF value and an associated indicator. The indicator is shown as DCI_{si}^{ci}, where ci is the carrier index, either **0** or **1**, and si is the subframe index.

DCI **508** may include a CIF value of 000 and an indicator DCI_0^0. By reference to table **300**, the indicator may identify a downlink resource of a PDSCH transmission in subframe **0** of the Pcell, i.e., carrier **0**, that is to include data directed to the UE **108**.

DCI **512** may include a CIF value of 010 and an indicator DCI_3^1. The indicator may identify a downlink resource of a PDSCH transmission in subframe **3** of the Scell, i.e., carrier **1**, that is to include data directed to the UE **108**.

Subframe **1** of the Pcell may include DCI **516**. DCI **516** may include a CIF value of 011 and an indicator $DCI_{1,4}^1$. The indicator of DCI **516** may identify a downlink resource of a PDSCH transmission in subframes **1** and **5** of the Scell. In this embodiment, the identified resource may be in the same position in both subframes.

Subframe **5** of the Pcell may include DCI **520**. DCI **520** may include a CIF value of 011 and an indicator $DCI_{5,8}^1$. The indicator of DCI **520** may identify a downlink resource of a PDSCH transmission in subframes **5** and **8** of the Scell.

Subframe **6** of the Pcell may include DCIs **524** and **528**. DCI **524** may include a CIF value of 000 and an indicator DCI_6^0 to identify a downlink resource of a PDSCH transmission in subframe **6** of the Pcell. DCI **528** may include a CIF value of 001 and an indicator DCI_6^1 to identify a downlink resource of a PDSCH transmission in subframe **6** of the Scell.

FIG. **6** is a flowchart illustrating an operation **600** of a user equipment, e.g., UE **108**, in accordance with some embodiments.

At block **604**, the operation may include receiving downlink control information. The DCI may be received by a decoder module, e.g., decoder module **124**, decoding resources within a PDCCH of a Pcell. In some embodiments, the decoder may blindly decode blocks within a particular search space to receive the DCI. Upon receipt of the DCI, the decoder module may then provide the DCI to a scheduling module, e.g., scheduling module **128**.

At block **608**, the operation **600** may include determining corresponding resource. In some embodiments, the determining may be performed by the scheduling module accessing a table and identifying a value within the table based on a CIF value of the DCI. The scheduling module may then identify a resource within a PDSCH that is to include data directed to the UE, based on the value from the table. This identification may be performed as described above. The scheduling module may communicate the identified resource to the decoding module.

At block **612**, the operation **600** may include receiving data. The receipt of the data may be performed by the decoder module decoding the resource of the PDSCH transmission identified by the scheduling module in block **608**.

FIG. **7** is a flowchart illustrating an operation **700** of a base station, e.g., eNB **104**, in accordance with some embodiments.

At block **704**, the operation **700** may include scheduling DCI and data. The scheduling may be done by a scheduling module, e.g., scheduling module **140**, scheduling the DCI in a PDCCH of a first subframe of a Pcell and the data into a PDSCH of a second subframe of the Scell. The DCI may identify the downlink resource carrying the data in the PDSCH of the second subframe of the Scell.

At block **708**, the operation **700** may include encoding DCI and data. The DCI and data may be encoded by an encoder module, e.g., encoder module **144**, encoding the DCI in the PDCCH of the first subframe of a Pcell and the data in the PDSCH of the second subframe of the Scell. The DCI may be encoded as a 3-bit CIF value.

At block **712**, the operation **700** may include transmitting the DCI and the data. The DCI and the data may be transmitted by a transmitter module, e.g., transmitter module **148**.

The modules described herein may be implemented into a system using any suitable hardware and/or software to configure as desired. FIG. **8** illustrates, for one embodiment, an example system **800** comprising one or more processor(s) **804**, system control logic **808** coupled with at least one of the processor(s) **804**, system memory **812** coupled with system control logic **808**, non-volatile memory (NVM)/storage **816** coupled with system control logic **808**, and a network interface **820** coupled with system control logic **808**.

The processor(s) **804** may include one or more single-core or multi-core processors. The processor(s) **804** may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, baseband processors, etc.).

System control logic **808** for one embodiment may include any suitable interface controllers to provide for any suitable interface to at least one of the processor(s) **804** and/or to any suitable device or component in communication with system control logic **808**.

System control logic **808** for one embodiment may include one or more memory controller(s) to provide an interface to system memory **812**. System memory **812** may be used to load and store data and/or instructions, for example, for system **800**. System memory **812** for one embodiment may include any suitable volatile memory, such as suitable dynamic random access memory (DRAM), for example.

NVM/storage **816** may include one or more tangible, non-transitory computer-readable media used to store data and/or instructions, for example. NVM/storage **816** may include any suitable non-volatile memory, such as flash memory, for example, and/or may include any suitable non-volatile storage device(s), such as one or more hard disk drive(s) (HDD(s)), one or more compact disk (CD) drive(s), and/or one or more digital versatile disk (DVD) drive(s), for example.

The NVM/storage **816** may include a storage resource physically part of a device on which the system **800** is installed or it may be accessible by, but not necessarily a part of, the device. For example, the NVM/storage **816** may be accessed over a network via the network interface **820**.

System memory **812** and NVM/storage **816** may respectively include, in particular, temporal and persistent copies of logic **824**. The logic **824** may include instructions that when executed by at least one of the processor(s) **804** result in the system **800** implementing one or modules, e.g., decoder module **124**, scheduling module **128**, scheduling module **140**, and/or encoder module **144**, to perform corresponding operations described herein. In some embodiments, the logic **824**, or hardware, firmware, and/or software components thereof, may additionally/alternatively be located in the system control logic **808**, the network interface **820**, and/or the processor(s) **804**.

System memory **812** and NVM/storage **816** may also include data that may be operated on, or otherwise used in conjunction with, the implemented modules. For example, one or more MSCC tables may be stored in system memory **812** and/or NVM/storage **816** and accessible by the modules for implementing MSCC scheduling operations described herein.

Network interface **820** may have a transceiver **822** to provide a radio interface for system **800** to communicate over one or more network(s) and/or with any other suitable device. The transceiver **822** may implement receiver module **120** and/or transmitter module **132**. In various embodiments, the transceiver **822** may be integrated with other components of system **800**. For example, the transceiver **822** may include a processor of the processor(s) **804**, memory of the system memory **812**, and NVM/Storage of NVM/Storage **816**. Network interface **820** may include any suitable hardware and/or firmware. Network interface **820** may include a plurality of antennas to provide a multiple input, multiple output radio interface. Network interface **820** for one embodiment may include, for example, a network adapter, a wireless network adapter, a telephone modem, and/or a wireless modem.

For one embodiment, at least one of the processor(s) **804** may be packaged together with logic for one or more controller(s) of system control logic **808**. For one embodiment, at least one of the processor(s) **804** may be packaged together with logic for one or more controllers of system control logic **808** to form a System in Package (SiP). For one embodiment, at least one of the processor(s) **804** may be integrated on the same die with logic for one or more controller(s) of system control logic **808**. For one embodiment, at least one of the processor(s) **804** may be integrated on the same die with logic for one or more controller(s) of system control logic **808** to form a System on Chip (SoC).

The system **800** may further include input/output (I/O) devices **832**. The I/O devices **832** may include user interfaces designed to enable user interaction with the system **800**, peripheral component interfaces designed to enable peripheral component interaction with the system **800**, and/or sensors designed to determine environmental conditions and/or location information related to the system **800**.

In various embodiments, the user interfaces could include, but are not limited to, a display (e.g., a liquid crystal display, a touch screen display, etc.), a speaker, a microphone, one or more cameras (e.g., a still camera and/or a video camera), a flashlight (e.g., a light emitting diode flash), and a keyboard.

In various embodiments, the peripheral component interfaces may include, but are not limited to, a non-volatile memory port, an audio jack, and a power supply interface.

In various embodiments, the sensors may include, but are not limited to, a gyro sensor, an accelerometer, a proximity sensor, an ambient light sensor, and a positioning unit. The positioning unit may also be part of, or interact with, the network interface **820** to communicate with components of a positioning network, e.g., a global positioning system (GPS) satellite.

In various embodiments, the system **800** may be a mobile computing device such as, but not limited to, a laptop computing device, a tablet computing device, a netbook, an ultrabook, a smartphone, etc. In various embodiments, system **800** may have more or less components, and/or different architectures.

In various embodiments, an apparatus, e.g., a UE, is described including a scheduling module configured to: receive, from a base station, DCI in a first subframe of a Pcell of the base station, the DCI to include a CIF value and an indicator to indicate a downlink resource of a PDSCH transmission that is to include data directed to the apparatus; and determine, based on a predetermined subframe pairing and the CIF value, that the PDSCH transmission is in a second subframe of an Scell. The apparatus may further include a decoder module configured to decode the downlink resource of the PDSCH transmission based on the indicator and said determination that the PDSCH transmission is in the second subframe of the Scell. The downlink resource may be a physical resource block in some embodiments.

In some embodiments, the predetermined subframe pairing may be a pairing between two subframes in each half-radio frame. For example, the pairing may be a pairing of subframe **0** and **3** or of subframe **1** and **4**.

In some embodiments, the scheduling module is further configured to access mapping information based on the CIF value and a carrier aggregation level; and determine, based on the mapping information, the indicator applies to a first paired subframe of the predetermined subframe pairing, a second paired subframe of the predetermined subframe pairing, or to both the first and second paired subframe of the predetermined subframe pairing. The mapping information may be stored in an MSCC table that provides mapping information for individual combinations of CIF values and carrier aggregation levels.

In some embodiments, the CIF value may be a 3-bit value having eight states; the carrier aggregation level may be two, three, four, or five; and the mapping information may identify the Pcell if the CIF value is a first state and the CA level is two, three, four or five; the first paired subframe of a first Scell if the CIF value is a second state and the CA level is two, three, four, or five; the second paired subframe of the first Scell if the CIF value is a third state and the CA level is two, three, four, or five; the first and second paired subframes of the first Scell if the CIF value is a fourth state and the CA level is two or three; the first paired subframe of a second Scell if the CIF value is the fourth state and the CA level is four or five; the first paired subframe of the second Scell if the CIF value is a fifth state and the CA level is three;

the second paired subframe of the second Scell if the CIF value is the fifth state and the CA level is four or five; the second paired subframe of the second Scell if the CIF value is a sixth state and the CA level is three; the first paired subframe of a third Scell if the CIF value is the sixth state and the CA level is four or five; the first and second paired subframes of the second Scell if the CIF value is a seventh state and the CA level is three; the second paired subframe of the third Scell if the CIF value is the seventh state and the CA level is four or five; and the first paired subframe of a fourth Scell if the CIF value is an eighth state and the CA level is five.

In some embodiments, the CIF value may be a 3-bit value having eight states; the carrier aggregation level may be two, three, four, or five; and the mapping information may identify: the primary serving cell if the CIF value is a first state and the CA level is two, three, four or five; the first paired subframe of a first Scell if the CIF value is a second state and the CA level is two, three, four, or five; the second paired subframe of the first Scell if the CIF value is a third state and the CA level is two, three, four, or five; the first and second paired subframes of the first Scell if the CIF value is a fourth state and the CA level is two, three, four, or five; the first paired subframe of a second Scell if the CIF value is a fifth state and the CA level is three, four, or five; the second paired subframe of the second Scell if the CIF value is a sixth state and the CA level is three, four, or five; the first and second paired subframes of the second Scell if the CIF value is the seventh state and the CA level is three; the first paired subframe of a third Scell if the CIF value is the seventh state and the CA level is four or five; the second paired subframe of the third Scell if the CIF value is an eighth state and the CA level is four; and the first paired subframe of the fourth Scell if the CIF value is the eighth state and the CA level is five.

In some embodiments, the CIF value may be a 3-bit value having eight states; the carrier aggregation level may be two, three, four, or five; the Scell may be a first Scell; and the mapping information may identify: the primary serving cell if the CIF value is a first state and the CA level is two, three, four or five; the first paired subframe of a first Scell if the CIF value is a second state and the CA level is two, three, four, or five; the second paired subframe of the first Scell if the CIF value is a third state and the CA level is two, three, four, or five; the first and second paired subframes of the first Scell if the CIF value is a fourth state and the CA level is two, three, four, or five; the first paired subframe of a second Scell if the CIF value is a fifth state and the CA level is three, four, or five; the second paired subframe of the second Scell if the CIF value is a sixth state and the CA level is three, four, or five; the first and second paired subframes of the second Scell if the CIF value is the seventh state and the CA level is three; the first and second paired subframes of the second Scell if the CIF value is the seventh state and the CA level is four; the first paired subframe of a third Scell if the CIF value is the seventh state and the CA level is five; the first paired subframe of the third Scell if the CIF value is an eighth state and the CA level is four; and the first paired subframe of the fourth Scell if the CIF value is the eighth state and the CA level is five.

In some embodiments, the scheduling module may be configured to determine that the PDSCH transmission is in the second subframe of the secondary serving cell based further on a predetermined subframe pairing of the first subframe and the second subframe.

In some embodiments, the Pcell and the Scell may include respective component carriers having different TDD configurations.

In some embodiments, a plurality of component carriers are aggregated for communication between the apparatus and the base station and the scheduling module is further configured to determine that the PDSCH transmission is in the second subframe of the secondary serving cell based further on a number of the plurality of component carriers.

In some embodiments, the Pcell utilizes a first common carrier and the Scell utilizes a second common carrier.

In some embodiments, the scheduling module may be further configured to access mapping information in an MSCC table based on the CIF value and a carrier aggregation level; determine that the PDSCH transmission is in the second subframe based on the mapping information; and determine, based on the mapping information, that another PDSCH transmission of a third subframe of the secondary serving cell is also to include data directed to the apparatus.

In other embodiments, an apparatus, e.g., an eNB, is described to include a scheduling module configured to: schedule DCI in a PDCCH of a first subframe of a first component carrier of a plurality of component carriers aggregated for communication between a user equipment and a base station; and schedule data for the user equipment in a PDSCH of a second subframe of a second component carrier of the plurality of component carriers, wherein the DCI is configured to identify the second subframe of the second component carrier and the second subframe occurs later in a frame sequence then the first subframe; and an encoder module configured to encode the DCI in the PDCCH and the data in the PDSCH.

In some embodiments, the transmitter module may be configured to transmit the DCI in the PDCCH and the data in the PDSCH.

In some embodiments, the encoder module may be configured to encode the DCI to include a CIF value, e.g., with 3-bits, to identify the second subframe and the second component carrier.

In some embodiments, a method is described to include identifying a downlink resource, in a first subframe of a first component carrier of a plurality of component carriers, that is to include data directed to a user equipment based on DCI received in a second subframe of a second component carrier of the plurality of component carriers, wherein the second subframe occurs earlier in a frame sequence than the first subframe; and decoding the downlink resource to receive data directed to the user equipment.

In some embodiments, the method may include accessing an MSCC table to retrieve mapping information based on a CIF value in the DCI and a carrier aggregation level; and identifying the downlink resource based on the mapping information.

In some embodiments, one or more computer-readable media having instructions that, if executed by one or more processors, cause an apparatus to perform various methods described herein.

Although certain embodiments have been illustrated and described herein for purposes of description, a wide variety of alternate and/or equivalent embodiments or implementations calculated to achieve the same purposes may be substituted for the embodiments shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that embodiments described herein be limited only by the claims and the equivalents thereof.

What is claimed is:

1. An apparatus comprising:

scheduling circuitry to:

receive, from a base station, downlink control information (DCI) in a first subframe of a primary serving cell (Pcell) of the base station, the DCI to include a carrier indication field (CIF) value and an indicator to indicate a downlink resource of a physical downlink shared channel (PDSCH) transmission that is to include data directed to the apparatus; and

determine, based on a predetermined subframe pairing and the CIF value, that the PDSCH transmission is in a second subframe of a secondary serving cell (Scell), wherein the second subframe is different from the first subframe; and

decoder circuitry to decode the downlink resource of the PDSCH transmission based on the indicator and said determination that the PDSCH transmission is in the second subframe of the Scell,

wherein the scheduling circuitry is further to:

access mapping information, stored in a multi-subframe cross-carrier (MSCC) table that provides mapping information for individual combinations of CIF values and carrier aggregation levels, based on the CIF value and a carrier aggregation level; and

determine, based on the mapping information, the indicator applies to a first paired subframe of the predetermined subframe pairing, a second paired subframe of the predetermined subframe pairing, or to both the first and second paired subframe of the predetermined subframe pairing.

2. The apparatus of claim 1, wherein the predetermined subframe pairing is a pairing between two subframes in each half-radio frame.

3. The apparatus of claim 2, wherein the pairing is of subframe 0 and 3 or of subframe 1 and 4.

4. The apparatus of claim 1, wherein the scheduling circuitry is to determine that the PDSCH transmission is in the second subframe of the secondary serving cell based further on a predetermined subframe pairing of the first subframe and the second subframe.

5. The apparatus of claim 1, wherein the primary cell and the secondary cell include respective component carriers having different time-division duplexing (TDD) configurations.

6. The apparatus of claim 1, wherein a plurality of component carriers are aggregated for communication between the apparatus and the base station and the scheduling circuitry is further to:

determine that the PDSCH transmission is in the second subframe of the secondary serving cell based further on a number of the plurality of component carriers.

7. The apparatus of claim 1, wherein the primary serving cell utilizes a first common carrier and the secondary serving cell utilizes a second common carrier.

8. The apparatus of claim 1, wherein the downlink resource is a physical resource block.

9. The apparatus of claim 1, wherein the scheduling circuitry is further configured to

determine that the PDSCH transmission is in the second subframe based on the mapping information; and

determine, based on the mapping information, that another PDSCH transmission of a third subframe of the secondary serving cell is also to include data directed to the apparatus.

10. The apparatus of claim 1, comprising a user equipment.

11. An apparatus comprising:

scheduling circuitry to:

receive, from a base station, downlink control information (DCI) in a first subframe of a primary serving cell (Pcell) of the base station, the DCI to include a carrier indication field (CIF) value and an indicator to indicate a downlink resource of a physical downlink shared channel (PDSCH) transmission that is to include data directed to the apparatus; and

determine, based on a predetermined subframe pairing and the CIF value, that the PDSCH transmission is in a second subframe of a secondary serving cell (Scell), wherein the second subframe is different from the first subframe; and

decoder circuitry to decode the downlink resource of the PDSCH transmission based on the indicator and said determination that the PDSCH transmission is in the second subframe of the Scell,

wherein the CIF value is a 3-bit value having eight states; the carrier aggregation level is two, three, four, or five; the Scell is a first Scell; and the mapping information is stored in a multi-subframe cross-carrier (MSCC) table and identifies:

the primary serving cell if the CIF value is a first state and the CA level is two, three, four or five;

the first paired subframe of the first Scell if the CIF value is a second state and the CA level is two, three, four, or five;

the second paired subframe of the first Scell if the CIF value is a third state and the CA level is two, three, four, or five;

the first and second paired subframes of the first Scell if the CIF value is a fourth state and the CA level is two or three;

the first paired subframe of a second Scell if the CIF value is the fourth state and the CA level is four or five;

the first paired subframe of the second Scell if the CIF value is a fifth state and the CA level is three;

the second paired subframe of the second Scell if the CIF value is the fifth state and the CA level is four or five;

the second paired subframe of the second Scell if the CIF value is a sixth state and the CA level is three;

the first paired subframe of a third Scell if the CIF value is the sixth state and the CA level is four or five;

the first and second paired subframes of the second Scell if the CIF value is a seventh state and the CA level is three;

the second paired subframe of the third Scell if the CIF value is the seventh state and the CA level is four or five; and

the first paired subframe of a fourth Scell if the CIF value is an eighth state and the CA level is five.

12. An apparatus comprising:

scheduling circuitry to:

receive, from a base station, downlink control information (DCI) in a first subframe of a primary serving cell (Pcell) of the base station, the DCI to include a carrier indication field (CIF) value and an indicator to indicate a downlink resource of a physical downlink shared channel (PDSCH) transmission that is to include data directed to the apparatus; and

determine, based on a predetermined subframe pairing and the CIF value, that the PDSCH transmission is in a second subframe of a secondary serving cell (Scell), wherein the second subframe is different from the first subframe; and decoder circuitry to decode the downlink resource of the PDSCH transmission based on the indicator and said determination that the PDSCH transmission is in the second subframe of the Scell,

wherein the CIF value is a 3-bit value having eight states; the carrier aggregation level is two, three, four, or five; the Scell is a first Scell; and the mapping information is stored in a multi-subframe cross-carrier (MSCC) table and identifies:

the primary serving cell if the CIF value is a first state and the CA level is two, three, four or five;

the first paired subframe of the first Scell if the CIF value is a second state and the CA level is two, three, four, or five;

the second paired subframe of the first Scell if the CIF value is a third state and the CA level is two, three, four, or five;

the first and second paired subframes of the first Scell if the CIF value is a fourth state and the CA level is two, three, four, or five;

the first paired subframe of a second Scell if the CIF value is a fifth state and the CA level is three, four, or five;

the second paired subframe of the second Scell if the CIF value is a sixth state and the CA level is three, four, or five;

the first and second paired subframes of the second Scell if the CIF value is the seventh state and the CA level is three;

the first paired subframe of a third Scell if the CIF value is the seventh state and the CA level is four or five;

the second paired subframe of the third Scell if the CIF value is an eighth state and the CA level is four; and

the first paired subframe of the fourth Scell if the CIF value is the eighth state and the CA level is five.

13. An apparatus comprising:

scheduling circuitry to:

receive, from a base station, downlink control information (DCI) in a first subframe of a primary serving cell (Pcell) of the base station, the DCI to include a carrier indication field (CIF) value and an indicator to indicate a downlink resource of a physical downlink shared channel (PDSCH) transmission that is to include data directed to the apparatus; and

determine, based on a predetermined subframe pairing and the CIF value, that the PDSCH transmission is in a second subframe of a secondary serving cell (Scell), wherein the second subframe is different from the first subframe; and

decoder circuitry to decode the downlink resource of the PDSCH transmission based on the indicator and said determination that the PDSCH transmission is in the second subframe of the Scell, wherein the CIF value is a 3-bit value having eight states; the carrier aggregation level is two, three, four, or five; the Scell is a first Scell; and the mapping information is stored in a multi-subframe cross-carrier (MSCC) table and identifies:

the primary serving cell if the CIF value is a first state and the CA level is two, three, four or five;

the first paired subframe of the first Scell if the CIF value is a second state and the CA level is two, three, four, or five;

the second paired subframe of the first Scell if the CIF value is a third state and the CA level is two, three, four, or five;

the first and second paired subframes of the first Scell if the CIF value is a fourth state and the CA level is two, three, four, or five;

the first paired subframe of a second Scell if the CIF value is a fifth state and the CA level is three, four, or five;

the second paired subframe of the second Scell if the CIF value is a sixth state and the CA level is three, four, or five;

the first and second paired subframes of the second Scell if the CIF value is the seventh state and the CA level is three;

the first and second paired subframes of the second Scell if the CIF value is the seventh state and the CA level is four;

the first paired subframe of a third Scell if the CIF value is the seventh state and the CA level is five;

the first paired subframe of the third Scell if the CIF value is an eighth state and the CA level is four; and

the first paired subframe of the fourth Scell if the CIF value is the eighth state and the CA level is five.

14. One or more non-transitory, computer-readable media having instructions stored thereon that, if executed by one or more processors, cause a user equipment to:

decode downlink control information (DCI) received from a base station in a first subframe of a primary serving cell (Pcell) of the base station, the DCI to include a carrier indication field (CIF) value and an indicator to indicate a downlink resource of a physical downlink shared channel (PDSCH) transmission that is to include data directed to the user equipment;

access mapping information, stored in a multi-subframe cross carrier scheduling (MSCC) table that provides mapping information for individual combinations of CIF values and carrier aggregation levels, based on the CIF value and a carrier aggregation level;

determine, based on the mapping information, the indicator applies to a first paired subframe of the predetermined subframe pairing, a second paired subframe of the predetermined subframe pairing, or to both the first and second paired subframe of the predetermined subframe pairing;

identify, based on application of the indicator, that the downlink resource of the PDSCH is in a second subframe of a secondary serving cell (Scell), wherein the second subframe occurs earlier in a frame sequence than the first subframe; and

decode the downlink resource to receive data directed to the user equipment.

15. The one or more non-transitory, computer-readable media of claim **14**, wherein the instructions when executed further cause the user equipment to:

identify the downlink resource based on a predetermined subframe pairing that pairs two subframes in each half-radio frame.

16. The one or more non-transitory, computer-readable media of claim **15**, wherein predetermined subframe pairing pairs subframes **0** and **3** or subframes **1** and **4**.

17. The one or more non-transitory, computer-readable media of claim **14**, wherein the CIF value is a 3-bit value.

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